

Battery Energy Storage Systems for the Grid – Introduction

An Online Continuing Education Course for Engineers

Course Number: E-2138

Credit: 2 Hours / 2 PDH / 2 CPD

Battery Energy Storage Systems for the Grid – Introduction

Erik Nogren, P.E.

1. Introduction

Battery Energy Storage Systems (BESS) are enabling the U.S. power grid to transform as intermittent energy sources like wind and solar have increased, which requires other power sources to become more dispatchable and flexible. Traditional storage technologies have existed for decades, like pumped hydroelectric storage (PHS); however, the evolution of BESS technology, dominated by lithium-ion-based systems, is able to offer much more rapid dispatch and the ability to scale between small and large applications. A BESS system's capability to store and release energy, provide steady, sustained power flow, or rapid cycling, and its scalability in terms of both power capacity and energy storage duration make it a unique asset to complement an evolving grid and power demands.

BESS operation involves an electrochemical reaction and process. The charging cycle involves the input of electrical energy to convert to chemical energy within the battery cells. The discharge cycle reverses this process and supplies power to the grid. Several BESS technologies and chemistries exist; however, the fundamentals of this process are the same. Lithium-ion batteries are most prevalent due to generally high round-trip efficiency (exceeding 90%), declining costs, and higher volume of cell manufacturers and supply relative to other chemistries, such as vanadium redox. Section 3 of this course will explore the available chemistry and its advantages and disadvantages.

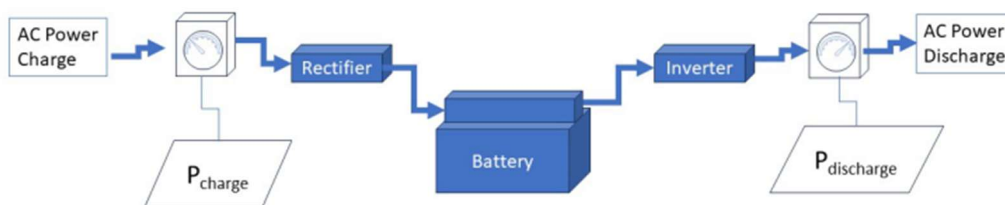


Figure 1: BESS Charge and Discharge Cycle (Source: DOE BESS Evaluation Method, December 2023)

BESS is poised to experience continued growth across the grid, with private corporations, the Federal government, Independent Power Producers (IPP), and utility companies all seeking the benefits of BESS. A primary driver for the growth has been the U.S. Inflation Reduction Act, which provides a minimum 30% tax benefit for BESS projects. This policy will be further discussed in this course. As costs continue to decrease and the need to decarbonize and manage the grid increases, the total installed capacity will continue to skyrocket up to as much as 150,000 MW by 2030.

2. BESS History

2.1 Historical Context

BESS applications are exponentially growing and becoming a critical cornerstone of the electrical grid. This section summarizes the origins of BESS, key developments in the technology, and general trends.

The modern era of battery storage started in the 18th century with Alessandro Volta's voltaic pile device. With this invention, Volta utilized stacks of alternating copper and zinc, separated by paper or cardboard soaked in electrolyte (saltwater). This combination produced a flow of electrical current, cementing its place in history as the first electrochemical battery. Volta's device, however, was not rechargeable and had limited capacity. In 1859, Gaston Planté developed the lead-acid battery, which was the first rechargeable device. Lead plates were submerged in sulfuric acid, allowing current to be reversed and producing the recharging effect.

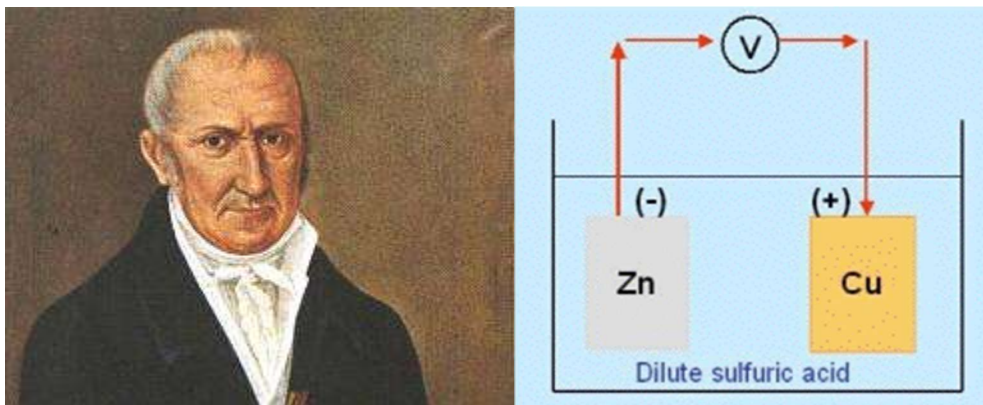


Figure 2: Alessandro Volta (Source: NASA.gov) Figure 3: The Voltaic Cell (Source: NASA.gov)

In 1899, the nickel-cadmium (Ni-Cd) battery was developed by Waldemar Junger, which generally offered improved energy density from lead-acid chemistry. The Swedish inventor was successful in gaining adoption, and this technology saw deployment in the US by the 1940's in portable devices and initial grid experiments. Along a similar timeline, Thomas Edison invented the nickel-iron (Ni-Fe) alkaline battery. This was designed for early concept electric vehicles and several stationary applications.

The 19th century set the stage for 20th-century applications on the electrical grid. The first storage applications mainly focused on mechanical storage (pumped hydro). World War II drove widespread use where lead-acid and Ni-Cd batteries to power submarines and offered Uninterruptible Power Supply (UPS) capabilities for critical infrastructure. In the 1960s, the Energy Storage Systems program was established at Sandia National Laboratories by the DOE. Several studies advanced early concepts for batteries to be deployed to support the electrical grid.

In 1981, Sony offered the first commercialized Li-ion battery in 1991. Li-ion offered longer life and higher energy density, and its first uses were in small electrical devices such as watches. The first applications for the grid were small, generally less than 100 kW; however, the timeframe from 2000 to 2010 saw an emergence of utility-scale storage. The need for utility-scale storage was driven by the exploding penetration of wind and solar power applications. The intermittency of these sources called for an asset class that could provide quick dispatchable energy.

Portland General Electric commissioned a 5 MW (1.25 MW-hour) system in 2012, which was the first utility-scale application of its kind. This was a lithium-ion-based system developed as part of a Department of Energy demonstration project. The system was integrated with a distribution feeder system and controlled by a central utility dispatch system to create a high-reliability zone. The system could operate in parallel with the utility grid or support an islanded system disconnected from the utility grid. This project was deemed the first “Microgrid” application supported by a utility-scale BESS system.

Note: BESS system capacity is typically expressed first as its power capacity, usually in kilowatts (kW) or megawatts (MW). This is the rate of power flow it can provide. The second term, its energy storage duration capability, is almost always expressed in hours. For example, a 1 MW 2 MW-hour system has a 1 MW power flow capacity and a 2-hour storage capacity (i.e., it can deliver 1 MW sustained discharge over 2 hours). 2 MWh / 1 MW = 2 hours.

2.2 Recent Growth

Today, BESS technology is a rapidly expanding grid asset that complements renewables (wind, solar, hydro), traditional fossil fuel power (coal, natural gas, diesel), and nuclear power. The Energy Information Administration (EIA) reported 26 GW of operating capacity in the U.S., representing a 66% increase in 2024 alone.

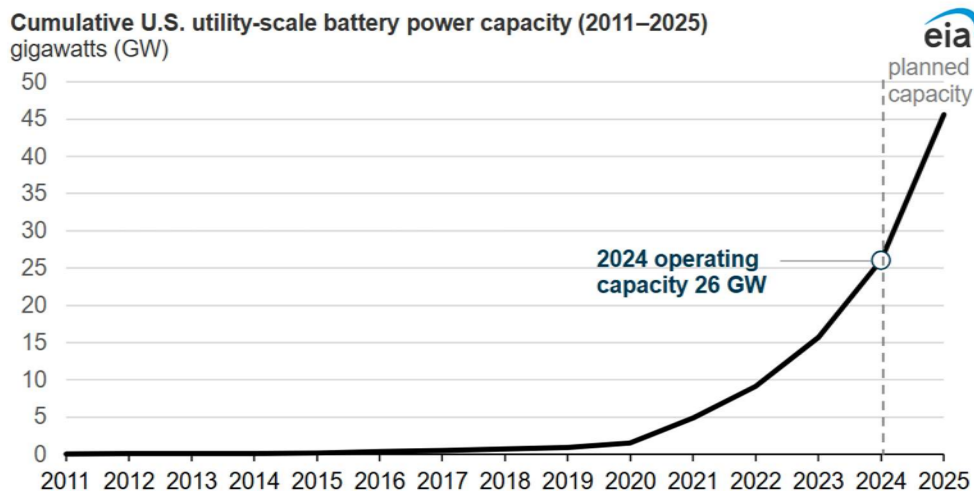


Figure 4: Cumulative BESS Capacity (Source: EIA)

For perspective, the total BESS capacity is a relatively small fraction (2%) of the total reported generating capacity in the U.S. as reported by EIA in 2024. For perspective on all generation sources, the Environmental Protection Agency provided these figures, which break down the electric generation in the U.S. by source as of 2023.

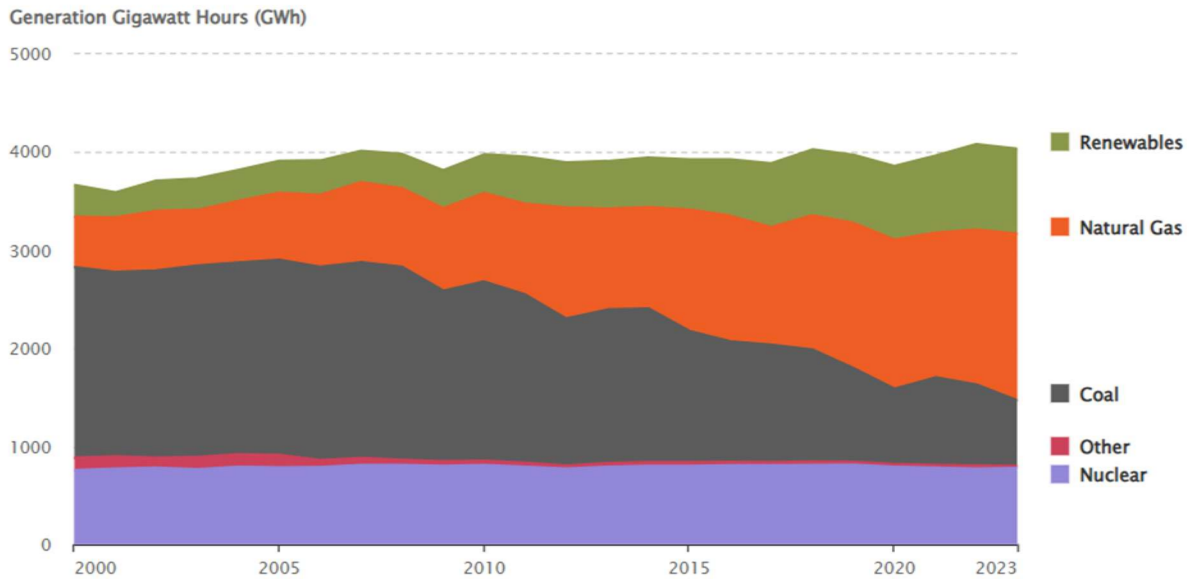


Figure 5: U.S. Generation by Source (Source: EPA)

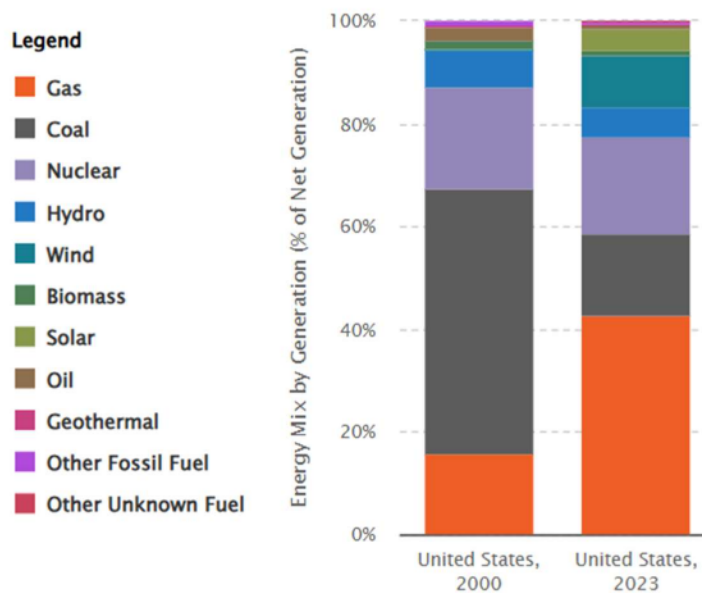


Figure 6: Generation by Source as a Percentage (Source: EPA)

It should be noted that BESS is not considered a generation source, as it does not generate its own electrical energy, but rather stores and discharges from other sources. Nonetheless, as the total capacity of BESS grows, it is expected that similar summaries conveying capacity profiles in the U.S. will begin to convey BESS as a contributing resource. As can be seen in Figure 6 above, coal has seen a rapid decrease as aging coal plants begin to retire, driven by renewable energy and emissions reduction goals across various states. From 2000 to 2023, coal decreased from roughly 45% of the total fuel mix to 15%. These retirements create the need for utility companies to replace the lost capacity with alternative resources. Although utilities are greatly increasing the amount of natural gas power to compensate, they are also showing a shift towards storage to diversify their resources.

This figure, provided by the EIA, gives a sense of where BESS additions in 2025 are concentrated. As can be seen, California and Texas continue to lead the country in BESS additions as they currently have the most lucrative power markets for BESS and generally have high renewable penetration on their transmission systems. As of 2025, California has approximately 16 GW of BESS capacity installed, and Texas has approximately 8 GW. The next highest state is Arizona with just under 2 GW.

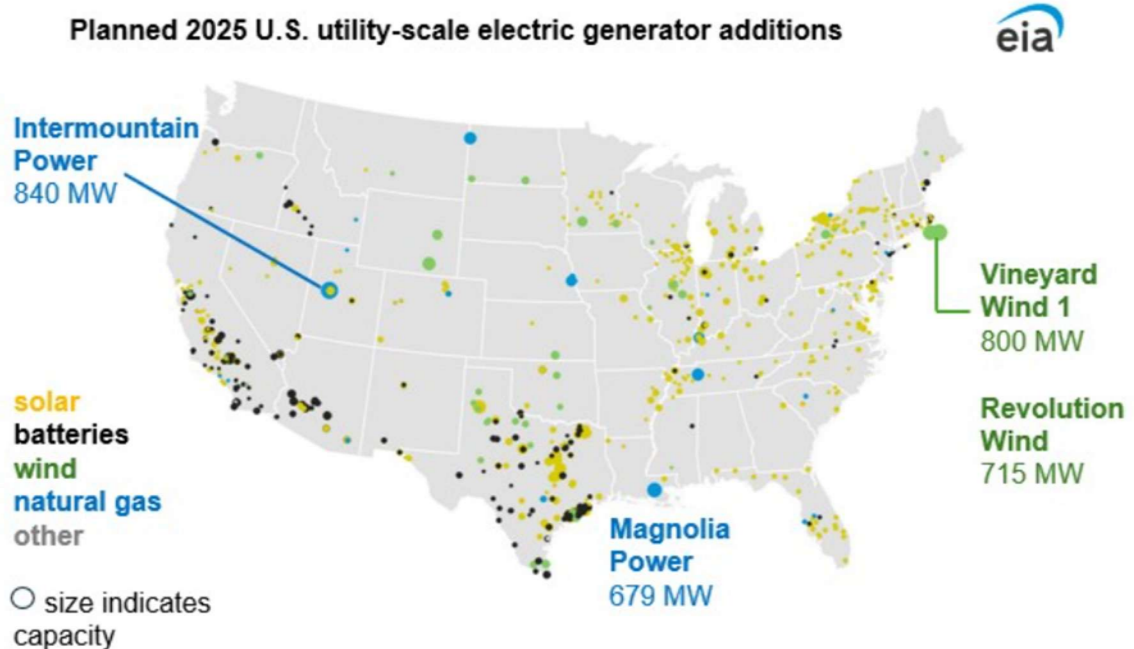
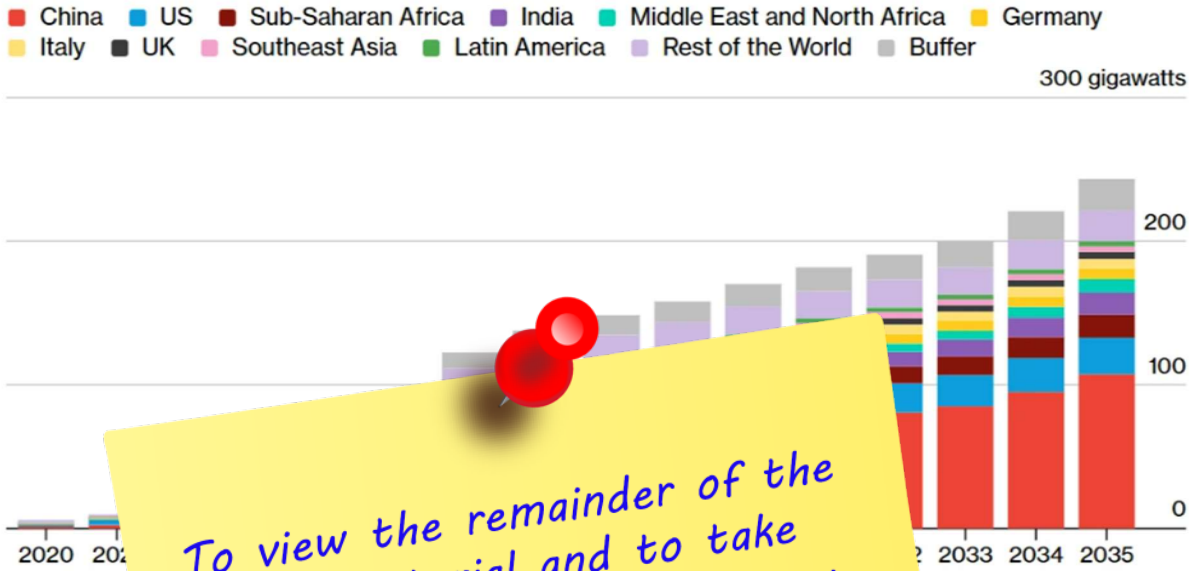


Figure 7: Planned 2025 U.S. Utility-Scale Generator Additions (Source: EIA)

Globally, energy storage is accelerating as well. The chart below displays the total storage additions by gigawatts (GW) by the leading nations. These figures exclude pumped hydro storage. China leads the way with over 50% of storage deployments, followed by the U.S., with around 15%.



To view the remainder of the course material and to take the quiz for PDH credit, you must purchase the course.

Close this window and click "Add to cart" on the product page.

2.3 BESS Policy

BESS policy remained relatively stable over the last decade. In 2025, the policy is expected to continue to support growth with benefits for the grid. The BESS section will cover the following:

... over the last decade. In 2025, the policy is expected to continue to support growth with benefits for the grid. The BESS section will cover the following:

On the Federal level, the Inflation Reduction Act (IRA), which had several provisions that extended the 30% Investment Tax Credit (ITC) to standalone storage projects. The full CAPEX of the project (labor plus equipment) is ultimately returned as a tax credit to the project owner. Developers will typically sell these tax credits to larger entities, typically large banks, with large tax obligations, in return for upfront cash that can be used to pay down construction debt. In addition to the 30% base tax credit, the IRA also offers ITC Bonus Zones, typically referred to as "Energy Communities", which can boost the tax credit by an additional 10% to a total of 40%. The IRS provides these definitions for the different types of energy communities that are available:

Labor Category: Metropolitan or non-metropolitan statistical areas with a minimum of 0.17% employment in the fossil fuel industry (coal, oil, or natural gas, including extraction, processing, transport, storage. This is applicable for any year after 2009. The MSA or Non-MSA must also have an unemployment rate at or above the national average for the year prior. MSAs and non-MSAs can fall in and out of the bonus each year as their labor participation rates change over time.